

ON THE ROLE OF GUESSWORK IN SCIENCE*

IS there a place in scientific inquiry for guessing? Among those who answer in the affirmative (Aristotle, Faraday, Tyndall, Whewell, Peirce, Hempel, Popper), opinions range from 'occasionally useful' to 'essential to discovery' to 'the essence of all scientific thinking'. On the negative side (Plato, Hanson, Cohen), the consensus is that guessing falls short of the level of rational thought worthy of the name science, and has therefore no proper role to play in scientific inquiry. Before the dispute can be resolved, we will have to examine the related questions of the nature of guessing and its relations to belief, evidence, and reasoning. I begin by considering Aristotle's modest affirmative proposal, arguably the first affirmative account ever¹, and conclude by weighing it against the negative view defended by Jonathan Cohen in his recent paper, *Guessing*².

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¹ Toulmin and Goodfield in the *Architecture of Matter*, pp. 76–77 claim that Plato recognized the need for 'intelligent guesswork', and base this claim on the following translation of *Timaeus*, 56b3–5: 'so we seem to have real (*i.e.* mathematical) grounds, as well as plausible guesswork, to justify choosing the pyramid from among the regular solids as the atom or seed of fire' (p. 77). But this translation of *Kata ton eikota* is unwarranted. *Ton eikota* here (like *eikotas* at 29c2, *eikota mython* at 29d2, *eikotas* at 44d1 and *ton eikoton logon* at 48d2) is simply what is likely or plausible (Cornford translates: 'in accordance with probability'), and is of a piece with the 'likely story' motif running through the entire account. There is no mention of guessing or guesswork. At best, the reference to 'hitting upon the answer' (at 53e3: *tuchontes echomen ten aletheian*) may suggest an element of lucky guessing, but *tuchano* often means simply to happen or succeed at doing. In general, Plato's position seems to have been that genuine science (*episteme*) is to be contrasted with proceeding by guesswork: if from any art you subtract the element of numbering, measuring and weighing, what would be left would be 'guesswork' (*eikadzein*) and rule of thumb-involving the ability to make lucky shots (*stochastikes*) (*Philebus*, 55e5). Medicine is not credited as wisdom (*sophia*) since it is 'at sea on an ocean of conjecture, without reduction to rule' (*Epinomis*, 976a4–5). Plato could have, perhaps should have, claimed that the account in the *Timaeus* was a piece of guesswork, but there is no evidence that this is what he did claim.

² L. Jonathan Cohen, 'Guessing', *Proceedings of The Aristotelian Society* (New Series), LXXIV (1973–74), pp. 189–210.

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I

It may come as a surprise to hear that Aristotle had an opinion about the role of guesswork in science, and for at least two reasons: first it has been widely believed that his main account of science, the *Posterior Analytics*, says nothing about scientific *inquiry* but is concerned exclusively with the axiomatic presentation of knowledge already acquired.³ Second, even if the account of science found in the *Analytics* and elsewhere does apply to inquiry and discovery, it is, one would have thought, the construction of syllogisms and the drawing of logical inferences, and not guesswork, that is involved. A full reply to both positions would lead us too far away from our topic, and I have argued elsewhere against the first. Let me instead simply summarize here the grounds for contending that the *Analytics* is concerned, at least in part, with the discovery of the universal principles of the various sciences.

(1) Aristotle speaks of the expansion or growth of scientific knowledge in two distinct ways: as a process of adding 'extreme' terms; *i.e.* applying the results of some demonstration to similar phenomena (*P.A.*, 78a14) and as a process of filling in 'middle' terms until we reach the 'unmiddled' ultimate premisses of the science (*P.A.*, 79a30, 84b19, 85b27, 90a34–35). The construction of syllogisms, in short, takes place on the way toward the discovery of the first principles and essential definitions of science as well as on the way down toward particular theorems and applications.

(2) Although 'inductive' and 'deductive' are adjectives frequently used to modify arguments, and even on occasion forms of instruction, there are passages where 'inductive' is used to describe the process by which the universal principle is first discovered, *i.e.* it is made known from repeated perceptions of particular cases. One such passage is the famous account at *P.A.* II, 19, where induction is spoken of as that whereby perception, *via* intuition, yields the universal. The same process is evidently also under view at 81b5:

. . . it is impossible to come to grasp universals except through induction. But induction is impossible for those who have not sense perception (Mure trans.).

(3) The discussion of definition and demonstration (*P.A.* II, 3,7,8,10) shows Aristotle's interest in the extent to which essential definitions are to be found, either by invention or by demonstration. The role assigned to definition (useful at least as a technique for specifying the subject of inquiry — *e.g.* the 'nominal definition' of thunder as a noise in the clouds and eclipse as a privation of light)

³ John Herman Randall comments: 'There is in the *Posterior Analytics* no concern with method and procedure: Aristotle's gaze is fixed entirely on what a completed and perfected science is like.' (*Aristotle*, New York, 1960, p. 33). A more radical view is promoted by Jonathan Barnes: 'the theory of demonstrative science was never meant to guide or formalize scientific research: it is concerned exclusively with the teaching of facts already won . . . a formal model of how teachers should impart knowledge.' ('Aristotle's Theory of Demonstration' *Phronesis*, XIV, 2 (1969), 138).

would be of no interest or importance if Aristotle were concerned solely with those sciences already in possession of their essential definitions.

(4) At least part of Aristotle's task in the *Analytics* is to find the proper account of those states of mind involved in the transition from perception of particular cases to the recognition of the universal principle which they embody and exemplify. One example of this is the discussion of the role of perception in knowledge at *P.A.* I, 31: scientific knowledge is not gained in the act of perception, nevertheless the absence of a sense can result in the loss of knowledge connected with it: if we could see "the pores in the glass and the light passing through, the reason for the kindling would be clear to us because we should at the same time see it in each instance and intuit (*noesai*) that it must be so in all instances" (88a14, Mure trans.).

There is then evidence in the *Posterior Analytics* of a double interest in scientific knowledge: the progression from perception, from things more knowable to us, to those things more knowable in themselves, the first principles of the science, and the progression from those principles to the derivations and applications which they provide. Granted, there are those instances when Aristotle seems clearly concerned with the finished science, perhaps 'science proper' (e.g. 85a35, 85b22, 100b10 ff.), but they do not justify rendering the *Analytics* as devoid of any interest in scientific discovery. A similar dual conception of science is present in other parts of the corpus; for example, the account of scientific thought at *Prior Analytics* 46a: it is first necessary for experience to supply us with the general principles, and up to us, once the phenomena are adequately apprehended, to find the relevant demonstrations (cf. *De Gen. et Corr.*, 316a5 ff.).

In the light of this, it is not surprising to find that when Aristotle does make brief mention of a possible role to be played by guesswork or conjecture, he does so in two ways, speaking both of its place in the search for the unmiddled premisses of syllogistic explanation, as well as in the drawing of inferences from the essential definitions of a science. This second role can be seen in the following from Book I, Chapter I of the *De Anima*:

. . . in all demonstration a definition of the essence is required as a starting point, so that definitions which do not enable us to discover the derived properties, or which fail to facilitate even a conjecture about them, must obviously, one and all, be dialectical and futile (402b25–403a2, Smith trans.).

This reference to 'conjecture' (*eikasai* — from *eikadzo*) is admittedly incidental; it is put forward merely as one feature of a definition which might prevent it from being completely futile; and this is hardly a recommendation for the use of conjecture. What Aristotle has in mind is that, in light of its role in demonstration, the scientifically useful essential definition must be more than just a true statement, and more than just a necessarily true statement, about a thing's essential properties; it must also allow for inferences to be drawn from

the statement of a thing's essence to various related properties; for example, from the definition of anger to the related physical symptoms of being angry.⁴ How is this a matter of *eikadzein*? *Eikadzein* carries with it some suggestion of the making of a comparison, or forming a conjecture based on some similarities, but there is no reason to limit the theoretical connection between essential definitions and derived properties to similarities. Ross translates 403a1 simply as 'or even to guess at the attributes', and *eikadzein* is similarly translated as 'guess' in Plato (e.g. by Jowett at *Philebus* 55E). *Eustochia*, *topadzein*, *stochadzesthai* all contain an element of hitting a mark, especially being good or lucky at doing so, and *eikadzein* is explicitly linked with *stochadzesthai* in the *Philebus* passage. While both Plato and Aristotle recognize that we sometimes do make such 'lucky shots', only the latter shows any inclination to recognize a place for it in so distinguished a matter as *episteme*, scientific knowledge. Here, *eikadzein*, while not a matter of *discovering*, is at least allowed as an inferior alternative.

The second passage, really a set of passages, involves the related notions of the search for a 'middle', 'quickness of thought' and guessing:

(Deliberation is not the same as) skill in conjecture (*eustochia*) for this (*eustochia*) both involves no reasoning and is something that is quick in its operation, while men deliberate a long time . . . Again readiness of mind (*anchinoia*) is different from excellence in deliberation, it is a sort of skill in conjecture (*esti d' eustochia tis he anchinoia*) (*N. Ethica*, 1142b2-8, translated by Ross).

While this passage establishes a connection between *anchinoia* and *eustochia*, nothing is said of the role of either in science. Indeed, the irrational or at least non-rational character of *eustochia* might be expected to rule out any close conceptual connection with *episteme*. Throughout Aristotle's writings, and indeed throughout much of Plato's, *episteme* is explicitly *meta logou* — involving reasoning. Yet in spite of this contrast of *eustochia* and *episteme*, the *Posterior Analytics* contain one remarkable passage where both *eustochia* and *anchinoia* seem to have some connection with scientific thinking. At I, 34, Aristotle speaks of *anchinoia* (literally 'near or ready thought') as a kind of guessing or conjecture (*eustochia*), namely, guessing the middle term immediately.⁵ One need only connect this mention of the middle term with Aristotle's claim that 'in all our inquiries we are asking either whether there is a middle or what the middle is' (*P.A.*, 90a5) to see that *anchinoia*, and thereby *eustochia* may have a central role to play. Of the three examples given at I, 34 however, only the first is drawn from a recognizably scientific context:

⁴The contrast with a merely 'dialectical' definition is not developed in any detail. Philoponus points out that the definition of anger, labelled as dialectical at 403a30 ('the appetite for returning pain for pain') is barren, while the physicist's definition ('the boiling of blood or warm substance around the heart') offers at least a prospect for explaining the related symptoms (palpitation, rise of temperature, flushed face, etc.). Haydruck (ed.) *Commentaria* 44, pp. 2–11.

⁵*he d'anchinoia estin eustochia tis en askeptoi chronoi tou mesou . . .*, 89b10–11.

(*anchinoia*) would be exemplified by a man who saw that the moon has her bright side always turned toward the sun, and quickly grasped the cause of this, namely that she borrows her light from him . . . Let A represent 'bright side turned sunward', B, 'lighted from the sun', C the moon. Then B, 'lighted from the sun', is predicated of C, the moon, and A, 'having her bright side towards the source of her light' is predicable of B. So A is predicable of C through B. (89b12 ff., Mure trans.).

So in spite of the fact that *anchinoia* and *eustochia* are very different from *episteme*, and could never be synonymous with it, they are at least compatible with *episteme*, and can play a role in the development of the scientific syllogism. There is evidently more to Aristotelian science than the methodical drawing of logical inferences from self-evidently true premisses.⁶ Aristotle recognizes that there may be some merit in the immediate and groundless 'lucky shot' when we are attempting to fill in the missing links of causal explanation, and he seems also to sanction the occasional speculative conjecture concerning the possible theorems and applications of the first principles of a science.

But we should be careful to avoid claiming a greater role for guesswork in the Aristotelian scheme than the bare minimum allowed by these passages. We should not for example take them as a precursor of Popper's views of science as simply consisting in, or consisting essentially in, guesswork.⁷ It is true that for Aristotle, *anchinoia* is defined as the ability to hit immediately upon a missing middle term. But it does not follow that all scientific inquiry would therefore involve *anchinoia*. This would follow if we must always be forced to guess at the missing middle term, but this is nowhere said. Aristotle certainly did share Popper's view that philosophy (both first and second philosophy) was best conducted when it incorporated a critical review of the theories of one's predecessor's, but he falls short of espousing Popper's principle of rational knowledge; *i.e.* that the essence of rational inquiry is a series of conjectures and refutations.

⁶This is not altogether new. The extra-syllogistic aspect of Aristotle's account of scientific thinking is discussed at length in Aryeh Kosman's 'Understanding, Explanation and Insight' in the *Posterior Analytics*, in *Exegesis and Argument (Phronesis Supp, I, 1973)* and in my 1973 paper on the meaning of *nous* in the *Posterior Analytics (Phronesis, XVIII, 1, 1973, 44-68)*. Among more general accounts, Losee's *Historical Introduction to the Philosophy of Science* (O.U.P., 1972) deserves mention. Losee mentions the passages at I, 34 (as most summarizers of Aristotle do not), and treats it as an instance of 'intuitive induction', analogous to the 'vision' of the trained taxonomist who is able to see the universal in the individual specimen. Neither Kosman nor Losee mentions the connection between *anchinoia* and *eustochia*.

⁷Remarks like 'all scientific statements are hypotheses, or guesses, or conjectures' are to be found frequently in Popper's works, especially in *Conjectures and refutations (New York and London, 1962)*. A similar view was proposed in the last century by John Tyndall in his *Faraday as Discoverer* (1868) reprinted by Thomas J. Crowell (1961): 'But this is the essence of all theory. The theory is the backward guess from fact to principle' (pp. 145-146). According to Tyndall, Faraday was 'always guessing by hypothesis' (p. 146).

Nor does Aristotle adopt the position defended by Hempel⁸ and others⁹ that scientific thought (if it is to be productive) must at least contain an element of guesswork. One might be tempted to argue that it was the doctrine of the *De Anima* (at least for the completion of a formal science), that any useful definition must facilitate guesses or conjectures about related properties, but this is not what he says. The thesis is merely that useful scientific definitions must either enable us to infer them outright or facilitate conjectures about them. Since the first disjunct may be satisfied by some definitions, this is considerably less than the imposition of guesswork as a necessary condition for productive scientific thinking.

Finally, Aristotle clearly did not think of guesswork, as Peirce did, as constituting a paradigm of scientific inference, nor did he display Peirce's enthusiasm and optimism for its employment.¹⁰ We do not even know if he expected it to be frequently or commonly present in scientific inquiry. He does not even mention a single, dateable, historical instance of a productive and respectable scientific guess. Nevertheless, he clearly believed that we had a capacity for making such guesses, and that some aspects of scientific explanation might be initially developed through its exercise. The actual occurrence of such a guess would have been for him neither philosophically mysterious nor intellectually disreputable.

II

Is there any merit in Aristotle's view of the nature and role of guesswork? We

⁸Carl G. Hempel, *Philosophy of Natural Science* (Englewood Cliffs: Prentice-Hall, 1966) pp. 15–17. 'scientific hypotheses and theories . . . constitute guesses at the connections that might obtain between the phenomena under study . . .' (p. 15), 'The discovery of important, fruitful, mathematical theories, like the discovery of important, fruitful theories in empirical science, requires inventive ingenuity, it calls for imaginative, insightful guessing.' (p. 17) Since Hempel allows for the 'inferring' of a hypothesis (in special and relatively simple cases) by mechanical procedures, and since he holds that guessing must be coupled with a thorough familiarity with current knowledge in the field, his position falls short of identifying *all* scientific thinking as guesswork.

⁹William Whewell in *Novum Organum Renovatum* (1858), p. 78: 'Hence advances in knowledge are not commonly made without the previous exercise of some boldness and license in guessing. The discovery of new truths requires, undoubtedly, minds careful and scrupulous in examining what is suggested; but it requires, no less, such as are quick and fertile in suggesting.' The chemist J. W. Mellor attributes to Newton the claim that 'no great discovery was ever made without a bold guess' (Mellor, *A Comprehensive Treatise on Inorganic and Theoretical Chemistry*, Vol. 1, p. 18), but fails to specify the source. A review of Newton's published works and private correspondence has not uncovered it.

¹⁰Peirce emphasized the importance of guesswork in scientific discovery, and coined the terms 'abduction' and 'retroduction' (following Aristotle's *apogoge*) to designate the activity of selecting that one hypothesis (from a large set of possible hypotheses) which would account for the phenomena under study, and which ought to be tested. The successes resulting from these 'backward guesses' were due, Peirce believed, to an affinity between man's mind and the processes of nature itself (see 'The Logic of Abduction' in *Charles S. Peirce: Essays in the Philosophy of Science*, Vincent Tomas (ed.) (New York, 1957), 235 ff.

can and do commonly make guesses about a variety of matters: the weather, the stockmarket, and where we left our keys. There are frequently guessing contests and guessing games, there are lucky guesses and educated guesses, obvious guesses and inspired guesses, good guesses and bad guesses, and correct guesses and incorrect guesses. Moreover, some recent accounts of guesswork have generally assumed, as Aristotle assumed about *eustochia* and *anchinoia*, that guessing is an irrational or at least non-rational activity. In contrast with Aristotle however, they have held that partly because of the non-rational character of guesswork, it has at best a minimal role in scientific inquiry.¹¹ Jonathan Cohen argues:

except in the case of very novel and pioneering inquiries, there is normally at least some relevant evidence available from the results of previous investigations in the same field, and it would obviously be foolish and irresponsible not to pay due attention to that evidence. But in very many cases this excludes the possibility of mere guesswork in the formulation of hypotheses though it is compatible with the possibility of conjecture (p. 209).

Guessing, in short, does not 'involve a judgment of evidence' (p. 198), it 'takes place when there is no evidence at all' (p. 210).¹² Further, guessing excludes 'consideration of reasons' (p. 197) and because one cannot guess on the basis of evidence, guesses 'are all, in a way non-reasonable, since they are a substitute for proper reasoning.' (p. 196). If Cohen is right, then whenever there is *some* evidence that bears on the topic of investigation, or whenever there is *some* line of reasoning followed by the inquirer, what is taking place cannot properly be termed guessing or guesswork. We may indeed have such a capacity, and it may operate much as Aristotle thought it did, but it has little or nothing to do with science.

A second obstacle in the path of 'scientific guesswork' is that:

... making a guess or conjecture that *p*, instead of just adopting the hypothesis that *p*, entails a slight but often undesirable diminution in the suspense of judgment

¹¹ Hanson seems to have thought something like this: because discovery can involve reasoning (e.g. in the selection of hypotheses) or exhibit patterns of reasoning, it is not a matter of guesswork, intuition, or hunch, and not to be left for discussion by the psychologist. I find it remarkable that Hanson, who argued at some length and with some animus that philosophers ought to pay more attention to the nature of discovery and related concepts, did not see that the concept of guessing also admitted of, and merited, philosophical attention. He seems to have dismissed guesswork as one of a number of 'large, dark, receptacles' into which we ought not to throw the discussion of scientific discovery (see for example his commentary on a paper by Gerd Buchdahl in *Scientific Change*, A. C. Crombie (ed.) (London, 1963), p. 461, and his comments on this topic in *Patterns of Discovery* (Cambridge U.P., 1969), pp. 85–87, 200.

¹² There is one complication: Cohen sometimes states the thesis in a weaker form: 'guessing is done when there is little or nothing to go on' (p. 202), guesses are 'typically' made without measurement or calculation (p. 193). The stronger version, let us call it the Exclusivity Thesis, is stated in six separate passages, and is in fact crucial to his argument. If we were to give up the Exclusivity Thesis, and allow the possibility of guessing on the basis of some evidence, or guessing in atypical cases on the basis of measurement and calculation then guessing would not be precluded when there was already some evidence available, and would not then be of potential utility only in very novel or pioneering circumstances. If guessing is going to be held to be unsuitable for general use in science, then the Exclusivity Thesis will have to be retained. My objections are therefore directed against the stronger but needed version of the thesis.

that professional prudence dictates at the stage at which a hypothesis has not yet been tested. (p. 209).

Guessing that p need not result in believing that p , but it does at least entail some inclination to believe that p , and that inclination is sufficient to jeopardize the professionally appropriate disinterested attitude. For both these reasons, Cohen concludes, guessing is not the professionally correct or most suitable method for arriving at testable hypotheses, and has, therefore, no 'intrinsic role to play in scientific method' (p. 209).

It would be a mistake to think of Cohen's view of the role of guesswork in science as the exact opposite of Aristotle's; the conclusion of Cohen's argument, for example, that guesswork plays no intrinsic (I take this to mean no essential) role, is one that is perfectly compatible with the *De Anima* and *Analytics* passages, and might, for all we can tell, be a view which Aristotle himself held. Moreover, Cohen allows for the occurrence of the occasional brilliant scientific guess or conjecture (p.209). But the same cannot be said for the premisses of Cohen's argument: if they are correct, then not even the modest Aristotelian proposal could be accepted; not only would guesswork be inessential, it would be impossible in almost every case, and inappropriate in every case.

But I think that Cohen's premisses are mistaken: guessing does not exclude judgments of evidence and rational inference, and it need not result in the loss of the professional disinterestedness which Cohen values. I will not attempt to argue for the very strong thesis that guesswork is essential to science but there do seem to be some datable instances of the useful and respectable scientific guess. The first task is to show that Cohen's premisses fail to rule out such cases *a priori*.

(A) *Guessing and evidence*

We obviously do sometimes guess when there is 'nothing to go on' (*i.e.*) the quick and groundless 'shots' that Aristotle designated as *eustochia* and this is true both with respect to the 'speech act' of guessing as well as with respect to the guesses made without an overt verbal performance. If, for example, someone asks me to guess the number they are thinking of between one and one hundred, unless I know in advance that they have an aversion to nines or a penchant for sevens, I will simply have to pick a number, make a 'blind guess' of a particular number, and say it. Similarly, if I have misplaced my keys, and have no clue as to their whereabouts, I will simply have to guess (though nothing needs to be said), and check to see whether my guess turns out to be right. But it seems equally clear to me that we sometimes do guess with something to go on.

If I am asked to guess the number of beans in the jar, it is likely that, not having counted them as they went in, I would have to guess at the right number. But it is not obvious that there is *nothing* for me to go on. A jar which is roughly ten inches high and six inches across, and which is filled to the top with beans is

certainly not going to contain only one bean, nor ten, nor ten million. And an 'intelligent guess' as to the right number, might be fashioned (uttered or not) by counting the number of beans visible in a small area and multiplying that figure by another thought to represent the relative magnitude of the jar. Cohen himself mentions a trivial case where one guesses 'the weight of a parcel holding it in your hands and using no balance or scales to measure it' (p.202), and here also there is *some* evidence available (namely, the felt weight of the parcel). The perceptible size, weight, condition, or qualities of an object may often provide valuable information on which to base a guess as to its actual size, weight, price, location, or nature.

Cohen concedes the existence of 'intelligent' or 'shrewd' guesses, but claims that these modifiers 'draw attention to the qualities or qualifications of the guesser rather than the guess' (p. 197). But it is irrelevant whether it is the guesser or the guess that is being highlighted; the fact remains that in cases of this sort, someone is making a guess, or guessing, in a way that is more informed, educated, or intelligent than it otherwise might have been. Moreover, it is difficult to see what the intelligence will consist in other than being able to fashion a promising guess from the very limited evidence available. Someone who makes an 'educated guess' early on election night, with only very early scattered returns (plus perhaps his years of experience as an election observer) may see in the initial data the tentative beginnings of a significant trend in the voting, even when others are as yet unable to reach such a conclusion. None of these examples are alleged to be paradigms of scientific analysis, but they do seem to constitute a class of guesses or guesswork that not only lies beyond the scope of Aristotelian *eustochia*, but counts against one of the two basic premisses of Cohen's argument.

It might however be objected that the kinds of guesses just mentioned are not really *bona-fide* guesses, but only quasi-guesses or guesses-loosely speaking. In order for something to count as a real guess, it is necessary that it be completely unfounded and irrational, a pure, sheer, or mere guess. Alternatively, if there is some evidence available, then what we are doing may be properly termed conjecturing, hypothesizing, estimating, suspecting, or jumping to a conclusion, but it is not guessing. To evaluate the objection we must first decide whether it is meant as a thesis about ordinary language and usage, or as a prescriptive proposal for how the term ought to be employed. If the former, the thesis seems false: the class of modifiers sheer, pure, mere, unfounded, wild, lucky, etc. are clearly not all synonymous, and hence they cannot each be redundant adjectives (*i.e.* if guessing simply meant 'unfounded guess' and it also simply meant 'lucky guess' then 'unfounded guess' would have to mean simply 'lucky guess', which it clearly does not). If they are not simply redundant adjectives then they serve to mark off a species of guesses from other species which are not pure, sheer, lucky, etc. Moreover, the contrasting class is also

positively characterized, as has been mentioned, as the class of educated, informed, intelligent, calculated guesses. If the thesis is meant as a descriptive or reportive definition, it must be rejected.

It may be however that what is ordinarily counted as a guess is not one simple sort of thing, but several different sort of activities, judgements, or beliefs, all confusingly included under the general rubric 'guessing'. If there was sufficient reason to keep the varieties distinct, there might also be good reason to restrict the legitimate range of cases to only a sub-set of those ordinarily countenanced as cases of guessing. There could be a good reason to develop a more precise or technical sense of guessing, and it also might be advisable to recognize as guesses only pure, unfounded or irrational guesses. Such a procedure might be well advised, but it would have this limitation: setting up a precise sense of guessing (Guessing) would not provide any basis for supporting Cohen's thesis about the role of guesswork in science. If it were true that only rational activities ought to have a part in scientific inquiry, and if Guessing were defined as a non-rational or irrational activity, then it would follow that Guessing would have no role to play in scientific inquiry; but it would not follow that guessing had no role to play, precisely because Guessing has been carved out of the range of cases normally thought of as instances of guessing. Thus, even if we were to accept the proposed definition of guessing (*i.e.* as a definition of guessing proper), the existence of all those other less proper but still recognizable cases of guessing would serve to refute Cohen's thesis about the role of guesswork in scientific inquiry. In particular, those 'impure' cases of guesswork would serve to undermine Cohen's premiss that guessing excludes consideration of evidence, even if Guessing would necessarily exclude consideration of the evidence.

(B) Guessing and reasoning

Cohen's argument links together evidence and reasoning so as to infer the absence of rational considerations from the absence of evidence, but this is implausible. Rational considerations could be present even when there is no evidence available, and though this has no special connection with guesswork, it is arguable that one's guesses might be connected with some process of reasoning even when there is no evidence to go on. Suppose, for example, that the Hope diamond is suddenly discovered to have disappeared, without the slightest clue as to how, when, or by whom. Are we to assume that no reasoning about its disappearance can take place unless some evidence is first uncovered? Is it not more likely that, in the absence of any existing evidence, some hard thinking will first be required to uncover some? One might begin the investigation by interviewing the staff to determine the last person to have seen the diamond, the last time at which it was seen, how many persons have access to the means for removing the diamond without doing damage to its container, etc. If Cohen were right, no reasoning could take place in such circumstances, but the

intelligent pursuit of evidence in cases of this sort makes that assumption dubious.

A simple-minded example of 'reasoned guessing' can be seen in the way in which guessing games, when played at all well, involve forethought, reflection, and inference making. To play "Twenty Questions" for example, one must learn to avoid overly specific guesses at the outset (e.g. is it the family cat?) and work intelligently toward a solution by a process of increasing specification. One's guesses must be framed in light of the success or failure enjoyed by previous guesses, and must frequently take into account the joint implications of the outcomes of several previous guesses. There are then more or less intelligent, reasonable, clever, perceptive, insightful, and astute ways of guessing — both at the outset when there is nothing to go on, and further along when information has been gained.

That 'rational guessing' is not confined to parlor games can be shown by reference to the following example incorporating some basic principles of information theory.¹³ Imagine that I am routinely required to locate a certain box containing a lead sample in every shipment of sixty-four boxes. Each box is identical in appearance and, when empty, weighs one pound. The box containing the lead sample weighs ten pounds altogether. Although I cannot weigh each box by hand, I can mechanically move them either singly or in a group to a scale which reads out the exact weight. I could of course begin with the box closest to me, have it put on the scale and see if weighs one pound or ten pounds. Alternatively, I could guess at random which box contained the lead sample. Each of these procedures would, on the average, require a total of thirty-two guesses before the right box was located. I might however proceed to weigh thirty-two of them at once. At the end of the first weighing, I will know in which group of thirty-two the box is located (*i.e.* if I happen to have picked the group including the heavy box, the total will be forty-one pounds; if the total is only thirty-two pounds, the heavy box is obviously in the other group). I then guess that it is in a particular sub-group of sixteen, then eight, then four, then two, then one. At each stage, a correct guess as to which group contains the heavy box conveys as much information as a wrong guess, and the right box can be located with only six guesses, saving, on the average, a total of twenty-six guesses. One can, in other words, guess wildly and at random, or with forethought and a rational strategy, both with respect to information already at hand and with respect to the general principles governing information

¹³My example is patterned after those given by Elwyn Edwards in *Information Transmission* (London, 1964), pp. 28–39. As Edwards explains, the optimal guessing strategy (in his examples, the optimal question asking strategy) provides a basis for measuring the amount of information contained in a given statement (that is, the number of yes–no questions required when the optimal strategy is employed).

measurement and communication theory. I do not know of an historical instance where a scientific experiment has been conducted with such an overall strategy in mind, but it has been proposed, on at least two occasions, that strategies of this sort ought to have an important place in the testing of scientific hypotheses.¹⁴ I conclude that Cohen's first reason for thinking that guesswork has no intrinsic role in science is mistaken: guessing can involve reasoning and judgements of evidence.

(C) *Guessing and believing*

If scientific guesswork is generally possible, is it also appropriate or, as Cohen claims, does it jeopardize the suspense of judgment valued in science? The value of the disinterested attitude is not without controversy, and Cohen admits that the committed pursuit of one's convictions is not without its virtues. If guessing did result in belief or an inclination to believe, it would still be possible to argue that such guesses were, on balance, of value to science. The sequence of events leading up to the discovery by Crick and Watson of the structure of DNA is a case in point. From the outset, the helical structure of DNA was thought to be the 'obvious guess'¹⁵; but what remained obscure was whether DNA was composed of one, two, or three strands, and if more than one, how the strands were bonded together. At one point, it was believed that it consisted of three helices with the backbones on the inside, and 'bivalent cations like Mg', 'provided the best guess' for the mechanism bonding together the phosphate groups (p. 62). As Watson comments, there was no evidence that the samples contained any bivalent ions, but 'there was absolutely no evidence against our hunch' (p. 62). This hunch however did not last for long, and was shortly to be undermined by the realization that ten times more water was required than allowed for in the model. The failure of this first guess, coupled with the rejection of the assumption that the backbones must be on the inside, was followed by a decision to attempt a two chain model with the chains held together by hydrogen bonds between the identical bases, adenine-thymine, guanine-cytosine. In short the first guess-hunch seems not to have blinded its authors to its shortcomings nor to have impaired the consideration of alternative structures. It is also worth noticing that in this case what transpired fits Aristotle's account of *anchinoia*: here, in the absence of evidence, a guess was made as to the causal mechanism linking the chemical properties of DNA with its helical structure. The whole process nicely illustrates the potential utility of the unsupported 'quick thought' of the missing theoretical link between the two

¹⁴The chemist W. D. Bancroft earlier in this century proposed that some reflection on research strategies be included in the advanced training of scientists; specifically, the economies to be gained by devising methods for halving at each stroke the number of testable hypotheses (*The Rice Institute Pamphlets*, 15 (1928), 167-352). Peirce made a similar recommendation: 'such an experiment, if it can be devised, at once halves the number of hypotheses' (*Essays*, p. 249).

¹⁵At least according to Watson's account in *The Double Helix* (New York: Atheneum, 1968), p. 41.

'extreme' terms. The guess of course turned out to be wrong, but, as Watson's account makes clear, it was not without its lessons.

In addition, there is good reason to doubt Cohen's claim that guessing entails a diminution of the professional prudent suspense of judgement. There seem to be several ways in which one can guess without entailing that one either believes or is inclined to believe what one has guessed to be the case. Clearly, when we are talking about the speech-act of guessing, it is possible to guess without the slightest inclination to believe. In general, it is difficult to see what my verbal performances could ever *entail* about my beliefs or inclinations to believe, and specifically, there are circumstances which show the contrary to be the case. Suppose that, while involved in a guessing game, I choose to try to lose the game. I might, for example, want my children to win the game, and so I guess badly on purpose — I guess answers that have already been given or which I know for various reasons to be wrong. I can then certainly guess, *i.e.* perform the speech-act of guessing that p without being inclined at all to believe that p is true.

For a different set of reasons, I could also guess 'mentally', *i.e.* with no overt verbal act, without a loss of suspense of judgment. Suppose that I am confronted with several possible options open, where each is as likely or unlikely as another, but where some option must be chosen. In such a circumstance, I might guess that one of them was the correct one, but without any temptation to believe this. A mundane example of this is well known to cross-word puzzle enthusiasts: the clue to 39 down says 'Boy's name — 3 letters', and the last letter must match up with the first letter of 40 across, 'Girl's name — 3 letters'. There are many possible combinations (Joe–Eve, Tom–Mae, Gus–Sue, *etc.*) and unless I am going to cheat by looking at the answer page, I will simply have to choose one of these combinations and see how well it matches up with the surrounding context. Even if the one I choose first turns out ultimately to be the right one, at the time I chose it, I needn't have had any such expectation. Nor is it necessary that at the time I guessed it, I was inclined to think that it was the correct guess to make: any of the others might have succeeded instead, and I chose it because I has to begin somewhere. If so, then guessing that p in this case would entail belief that p nor an inclination to believe that p .

We should also observe in passing that in cases like this (where one can guess without being inclined to believe that one has guessed correctly) it is also easy to see that guesses must be distinguished from hunches. One may sometimes guess what one has a hunch is true, but this need not be so, as can be seen from the fact that we could make a particular guess at the puzzle solution without having any hunch that it would be the correct solution. In general, there are important differences between guesses and hunches, so that while hunches may entail some inclination to believe, or may be somewhat involuntary (*i.e.* one cannot choose

one's hunches) we cannot infer from this that the same holds true for our guesses.¹⁶ We speak of guesses and hunches in quite a different manner: while there is a nominative form for both, there is no parallel verbal form; there is a verb 'to guess' but there is no verb 'to hunch', nor is there an activity of hunching. We make a guess but do not make a hunch, and there is guesswork but not hunchwork. We can guess quickly or deliberately, but we cannot have a hunch quickly or deliberately. If we operate on the assumption that guesses and hunches are identical, we will not likely wind up with a correct conception of either.

It might however be objected that there is a logical gap in the argument: even if guessing and guesswork, as we ordinarily encounter it in non-scientific contexts (e.g. in games and puzzles) can occur without a commitment or inclination to believe, it would not follow that the same held true for the guesses of the professional scientist. It is therefore worth noting that the 'puzzle solving' or 'game playing' kind of guesswork is not unknown in the history of science. Perhaps the most famous case is that of Mendeleev's discovery of the periodicity of the elements, and the development of the periodic table. Mendeleev speaks of science as involving 'conjectures' and 'presentiments', and at one point he mentions that the systematic arrangement of elements will allow some analogies between the elements to become visible, and others 'can be guessed in advance so to speak'.¹⁷ He also speaks on several different occasions of the 'decisions' that were made in the development of the various achematic arrangements of the elements. It is clear that the basic principle underlying the periodic table, that the orderly arrangement of elements in increasing atomic weight displayed periodic properties of the elements, was not a matter of guesswork, but was well supported by several groups within the table. But some elements were sufficiently unknown to make classification difficult, and there were places where some elements seemed to be missing. His 1869 paper in the *Journal of the Russian Chemical Society* provides no less than seven different possible periodic tables, each with various advantages and disadvantages. Even more striking are the drafts on which the various systems were first worked out: full of changes, deletions, substitutions, etc. J. W. van Spronsen comments, 'Mendeleev arrived at the periodic system by puzzling with little cards on which the names of the elements were written, a method which Kedrov (in his history of Mendeleev's discovery) very characteristically called patience.'¹⁸

¹⁶ Cohen seems to identify guesses and hunches (e.g. on p. 208 in his attempt to distinguish guessing and hypothesizing) and it may be that his mistaken identification lies behind his view that a man cannot choose his guesses. The puzzle example shows, I think, one circumstance in which we could easily choose what to guess as well as whether to guess or not.

¹⁷ 'The Relations Between the Properties of Elements and Their Atomic Weights', *The Journal of the Russian Chemical Society* reprinted in *Moments of Discovery* (New York: Basic Books, 1958), pp. 821–836.

¹⁸ from *The Periodic System of Chemical Elements* (New York:, Elsevier 1969), p. 134.

I conclude that both of Cohen's premisses are mistaken: guessing can involve judgements of evidence and reasoning, and it need not entail a loss of a prudent suspension of judgment. The basis for my argument has been a series of counter-examples drawn from the ways in which we sometimes speak of guessing and guesswork and the ordinary circumstances in which guessing sometimes plays a role. My assumption throughout has been that if we are to determine the role of guesswork in science we should first remove some misunderstandings concerning the concept of guessing, and that we can do that by reflecting on what is involved in those circumstances in which guessing ordinarily takes place. Specifically, I have argued that there is no conceptual barrier to the general utility of guesswork in science of the sort proposed in Cohen's argument, and we have mentioned two specific instances of the fruitful scientific guess. The result is, I think, a vindication of Aristotle's belief that scientific understanding might be advanced by the occasional 'quick thought' or 'lucky shot', either as part of the search for missing explanatory links or as an application of an established general principle. It is perhaps true that Aristotle's proposal was rather modest; it does lack some of the glamor of more sweeping assertions about the essential role of guesswork in all scientific thinking. On the other hand, Aristotle's proposal does seem to have the solid virtue of being right.

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